AFCEC-CX-TY-TR-2014-0033

EVALUATION OF THE AMEREX MODEL 775 WHEELED EXTINGUISHER WITH NOVEC 1230

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Contract No. FA8051-14-P-0010

November 2014

AIR FORCE CIVIL ENGINEER CENTER
READINESS DIRECTORATE

■ **Requirements & Acquisition Division** ■ **United States Air Force** ■ **Tyndall Air Force Base, FL 32403-5323**

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
18-NOV-2014

2. REPORT TYPE
Final Technical Report

3. DATES COVERED *(From - To)*
1-MAR-2014 -- 1-AUG-2014

4. TITLE AND SUBTITLE
Evaluation of the AMEREX Model 775 Wheeled Extinguisher with Novec 1230

5a. CONTRACT NUMBER
FA8051-14-P-0010

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
X14PL001

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

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Readiness Directorate
Requirements and Acquisition Division
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10. SPONSOR/MONITOR'S ACRONYM(S)
AFCEC/CXA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFCEC-CX-TY-TR-2014-0033

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Ref Public Affairs Case # AFCEC-201501, 7 January 2015. Document contains color images.

14. ABSTRACT
As part of an ongoing effort to identify a replacement for the Department of Defense (DOD) Halon 1211 flightline extinguisher, the Air Force Civil Engineer Center (AFCEC) performed a series of tests to evaluate the performance of the Amerex Corporation model 775 wheeled extinguisher containing the Novec 1230 firefighting agent manufactured by 3M. This test series consisted of ten rear engine fire tests, ten access panel fire tests, and one stream reach test. Overall, the Amerex model 775 extinguisher demonstrated the ability to extinguish both three-dimensional and hidden fires and was shown to have a stream reach distance that exceeds throw range requirements established in an earlier joint Air Force-Navy project.

15. SUBJECT TERMS
Flightline Extinguisher, Halon 1211, Novec 1230.

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	SAR	25	John Hawk
					19b. TELEPHONE NUMBER *(Include area code)* 850 283-3736

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1. SUMMARY

As part of an ongoing effort to identify a replacement for the Department of Defense (DOD) Halon 1211 flightline extinguisher, the Air Force Civil Engineer Center (AFCEC) performed a series of tests to evaluate the performance of the Amerex Corporation model 775 wheeled extinguisher containing the Novec 1230 firefighting agent manufactured by 3M. This test series consisted of ten rear engine fire tests, ten access panel fire tests, and one stream reach test.

The Amerex extinguisher successfully extinguished nine out of ten rear engine fires in an average time of 21 s using an average of 132 lb (88 percent of extinguisher capacity) of Novec in each fire.

The Amerex extinguisher successfully extinguished nine out of ten access panel fires in an average time of 15 s using an average of 81 lb (54 percent of extinguisher capacity) of Novec in each fire.

During the stream reach test, the extinguisher demonstrated the ability to extinguish small fires at a distance of at least 30 ft from the nozzle. This exceeded requirements on effective throw range of 25 ft specified in a joint Air Force–Navy project for the Environmental Security Technology Certification Program (ESTCP) that looked at potential replacements for the Halon 1211 flightline extinguisher.

Overall, the Amerex model 775 extinguisher demonstrated the ability to extinguish both three-dimensional and hidden fires and was shown to have a stream reach distance that exceeds throw range requirements established in an earlier joint Air Force–Navy project.

2. INTRODUCTION

2.1. Background

It has been estimated that there are currently 20,000 flightline fire extinguishers at DOD installations, primarily at airfields operated by the U.S. Air Force (USAF), Navy and Marine Corps. The current DOD flightline extinguisher uses Halon 1211, an ozone depleting substance (ODS). Under the terms of the Montreal Protocol and the U.S. Clean Air Act, the production of Halon 1211 ceased in 1993. DOD maintains a stockpile of Halon 1211 under the Defense Logistics Agency (DLA) Defense Reserve. Annual consumption of Halon 1211 for flightline applications is estimated to be as high as 200,000 lb per year. Based on the size of the DLA reserve, the stockpile could be depleted in less than ten years (1). Planned restrictions on the use of Halon 1211 in other countries may require an USAF alternative agent/extinguisher sooner.

The existing Halon 1211 flightline extinguishers were procured by DOD using a purchase description prepared by Warner Robins ALC (2). Figure 1 shows the current unit.

Figure 1. Amerex Model 600 DOD Halon 1211 Flightline Extinguisher

The extinguisher holds 150 lb of Halon 1211, which is discharged through a hand-held nozzle connected to 50 ft of ¾-in hose. The agent container is of the stored pressure type, using nitrogen as the pressurizing medium. The overall discharge time is approximately 48 s, yielding an average flow rate over the entire discharge of 3.1 lb/s. The unit has a 30A:240B:C rating from Underwriters Laboratory (UL) based on UL Standard 711 (3).

AFCEC desires to identify and select an alternative agent and/or a dispensing system to replace the existing 150-lb Halon 1211 flightline units.

A test protocol was previously designed and Halon 1211 was evaluated to determine the ability of the agent to extinguish pooled and flowing fuel tailpipe fires and a hidden engine fire. This was documented in a USAF/Air Force Research Laboratory (AFRL) report on establishing minimum performance requirements for USAF flightline fire extinguishers (4) as well as a follow-up USAF/AFRL report documenting the performance of the current Halon 1211 extinguisher (5).

Because any agent used in an extinguisher proposed for testing would be considered a replacement for an ODS, under Section 612 of the Clean Air Act of 1990 the agent would have to be approved as an acceptable Halon 1211 replacement through the Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) program prior to testing.

In previous ESTCP testing, criteria used in selecting candidate agents for testing included (1):

- Agent must be “clean” (leave no residue and be electrically non-conductive)
- Agent must not be a Class I or Class II ODS
- Agent atmospheric lifetime must be less than 250 years
- Agent global warming potential (GWP) must be less than 10,000
- Agent could not increase safety or occupational health risks
- Agent had to possess known effectiveness on both Class A and B fires
- Agent had to demonstrate an effective throw range of no less than 25 ft.

Previous USAF/AFRL efforts have examined the effectiveness of several firefighting agents and extinguisher platform combinations, as well as baseline performance measurements using the current DOD Halon 1211 extinguisher (5). Previously tested agents include the firefighting agents HFC-236fa (Dupont trade name FE-36) and HFCF Blend B (American Pacific Corporation trade name Halotron 1). Previously tested extinguishers include hardware manufactured by Ansul Incorporated, Buckeye Fire Equipment Company, and Amerex Corporation. None of these agents and extinguishers met the fire extinguishment equivalency criteria described in the test protocol.

Amerex Defense recently began marketing the Amerex model 775 extinguisher, a wheeled fire extinguisher containing the Novec 1230 agent manufactured by 3M, as a replacement for the Halon flightline extinguisher to meet the requirements of *National Fire Protection Association (NFPA) Standards 407: Standard for Aircraft Fuel Servicing* and *410: Standard on Aircraft Maintenance* (6), (7). This report describes the evaluation of this extinguisher/agent combination. Three test procedures were conducted: the rear engine fire test, the access panel fire test, and the stream reach test. The results are compared with the results from previously evaluated extinguisher–agent combinations and the current Halon flightline extinguisher standard.

AFCEC proposed a revised approach to the Halon flightline extinguisher replacement evaluation process as it appeared that an agent and extinguisher meeting or exceeding the equivalency/alternative criteria was not likely to be found. AFCEC proposed that the data from all the previously tested agents/extinguishers and the data from the Amerex model 775 be compared not on a pass/fail basis but on a best performance basis. Based on this comparison, the Air Force Fire Protection Panel can determine based on best performance if any of the commercially available agents/extinguishers provide an acceptable level of mission protection to be employed on USAF flightlines.
Performance considerations:

- NFPA Compliance (NFPA 407, section 5.13.4, (6))

- 80 B:C rating
    - 125 lb agent
- SNAP Approved for portable extinguishers
- Air Force Performance Test (AFRL-ML-TY-TR-02-4540. (4))
    - Engine Nacelle
    - Engine Concealed
- Weight and Cube (Technical Order 13F4-4-121, (8))
    - Weight: 165 lb±15 lb (empty)/315 lb±15 lb (filled)
    - Cube: 59 × 29 × 36 in

2.2. Description of Extinguisher

The Amerex Model 775 wheeled fire extinguisher is shown in Figure 2. The manufacturer's specifications for the Model 775, as well as a DOD Halon extinguisher (the Amerex Model 600) are presented in Table 1 (6). Physically, the model 775 is very similar to the Halon 1211 extinguisher, having an identical carriage but with a somewhat longer and narrower cylinder.

The model 775 is 3 in taller, 4 in deeper and 40 lb heavier than the model 600. Both extinguishers hold 150 lb of their respective agent. Both extinguishers are pressurized with nitrogen to expel their extinguishing agent, the model 775 operating at 125 psi compared to the Halon 1211 extinguisher operating at 200 psi. The model 775 has a 40-ft long, 1-in hose, which is somewhat shorter than the 50-ft long, ¾-in hose on the Halon 1211 extinguisher. The listed discharge range for the model 775 is 30 ft, whereas the Halon 1211 extinguisher range is given as being 30–40 ft. The listed discharge time for the model 775 is 22 s, giving it an average discharge rate of 6.8 lb/s (compared to 40 s and 3.1 lb/s for the Halon 1211 extinguisher). The model 775 extinguisher has a 3A:80B:C rating from UL based on UL Standard 711 (3).

Figure 2. Amerex Model 775 Wheeled Fire Extinguisher

Table 1. Manufacturer's Specifications for the Amerex Model 775 Extinguisher and the DOD Halon 1211 Extinguisher

Specifications	Amerex Model 775	DOD Halon 1211 (Amerex Model 600)
Model Number	775	600
Agent	Novec 1230	Halon 1211
U/L Rating	3A:80B:C	30A:240B:C
Capacity (lb)	150	150
Shipping Weight (lb)	355 (filled) 205 (empty) ±15	315 (filled) 165 (empty) ±15
Discharge Time (s)	22	48
Cylinder—DOT 4BW240 Operating Press (psi) Test Pressure (psi) Burst Pressure (minimum-psi)	 125 480 960	 200 480 960
Discharge Range (ft)	30	30–40
Operating Temp. Range (°F)	-40 to +120	-65 to +120
Safety Disc Burst Range (psi)	400–500	400–500
Hose Length (ft)	40	50
Hose Diameter (in)	1.0	0.75
Wheels (semi-pneumatic) (in)	16 × 4	16 × 4
Height (in)	62	59
Width (in)	29	29
Depth (in)	40	36
NSN	4210-01-610-6985	4210-01-140-2233

2.3. Description of Agent

Novec 1230 is a firefighting agent manufactured by 3M. It is composed of a single chemical compound, dodecafluoro-2-methylpentane-3-one, with the chemical formula $CF_3CF_2C(O)CF(CF_3)_2$. Novec 1230 is a liquid at room temperature (with a boiling point 49.2 °C / 120.6 °F). However, it has a very low heat of vaporization (88.0 kJ/kg), meaning it evaporates rapidly, even at temperatures well below its boiling point. For comparison, Halon 1211 has a heat of vaporization of 121 kJ/kg, while water has a heat of vaporization of 2,260 kJ/kg, approximately 25 times that of Novec 1230. When discharged through a nozzle under pressure Novec 1230 very rapidly transitions to the gaseous phase.

Gaseous mixtures of Novec 1230 and air have a much larger heat capacity than air alone. The primary method of extinguishment for Novec 1230 is the removal of heat from the combustion zone in the fire, which causes the combustion zone to cool to the point where it no longer supports fire. Typical concentrations required for extinguishment of flammable liquids are in the range of 4.5 to 8.5 percent, based upon cup burner tests (7).

Novec 1230 has an ozone depletion potential (ODP) of zero and a GWP of 1. By comparison, Halon 1211 has an ODP of 4 and a GWP of 16. Novec 1230 has been approved for nonresidential use by the EPA as an alternative to Halon 1211 under the SNAP program.

Novec 1230 exhibits very low dermal, inhalation, and oral toxicity. However the combustion products of Novec 1230 include very toxic and acidic gasses such as hydrofluoric acid and carbonyl fluoride. Novec 1230 may pose an asphyxiation hazard if an excess amount of agent is discharged in a confined space. Halon 1211 has similar toxicity and hazard characteristics.

Additional manufacturer's specifications for Novec 1230 are presented in Table 2 (7).

Table 2. Manufacturer's Specifications for 3M Novec 1230 Firefighting Agent

Specifications	Novec 1230
Chemical formula	$CF_3CF_2C(O)CF(CF_3)_2$
Molecular weight	316.04 g/mol
Boiling point @ 1 atm	49.2 °C (120.6 °F)
Freezing point	-108 °C (-162.4 °F)
Density, sat. liquid, 25 °C	1.60 g/mL (99.9 lbm/ft^3)
Density, gas @ 1 atm	25 °C 0.0136 g/mL (0.851 lbm/ft^3)
Specific volume @ 1 atm	0.0733 m^3/kg (1.175 ft^3/lb)
Liquid viscosity @ 0°C/25 °C	0.56/0.39 centistokes
Heat of vaporization @ Boiling Point	88.0 kJ/kg (37.9 Btu/lb)
Solubility of H_2O in Novec 1230 fluid	<0.001% by wt
Vapor pressure @ 25 °C	0.404 bar (5.85 psig)
Relative dielectric strength @ 1 atm (N_2=1.0)	2.3
Ozone Depletion Potential	0
Global Warming Potential	1
Atmospheric Lifetime (Years)	0.014
SNAP (Yes/No)	Yes
Use Concentration	4.5–6 %
NOAEL	10 %

3. METHODS, ASSUMPTIONS, AND PROCEDURES

3.1. Rear Engine and Access Panel Fire Tests.

Rear engine fire tests and access panel fire tests were performed using the F-100 nacelle test fixture located at the Silver Flag test site (Figure 3). The fixture is a cylinder 16 ft long that contains an inner cylinder (the space between the cylinders is termed the annulus) and three baffles positioned along the inside of the inner cylinder. The fixture is equipped with three spray nozzles that allow fuel to flow into different regions of the nacelle to simulate different fire scenarios. The nacelle sits atop a concave concrete pad that can collect a pool of jet fuel as part of the fire scenario. Design details and test protocol using this fixture are described in AFRL-ML-TY-TR-02-4540 (4) and AFRL-ML-TY-TR-2002-4604 (8).

Figure 3. The F-100 Nacelle Mock-Up Used for Rear Engine Testing and Access Panel Testing. In This Photo, Fuel *is* Flowing through the Nacelle in Preparation for a Rear Engine Test

During the rear engine tests and access panel tests, the Amerex 775 extinguisher was positioned on a scale so that the mass could be monitored during the test (Figure 4). A computer and data acquisition system was coupled to the scale to record mass data at a rate of one data point per second. This was done to facilitate filling the extinguisher with the proper amount of agent before each test, and to allow calculation of the mass of agent used and discharge rate of agent during each test. The scale accuracy was ± 1 lb.

Figure 4. The Amerex 775 Extinguisher Resting on a Scale during Preperations for a Rear Engine Test

Two tripod-mounted video cameras were set up to record each test from two different angles. A tripod-mounted Kestrel weather meter was also used to monitor the ambient temperature, humidity, and wind speed and direction. Testing was performed only when wind speed was 8 mph or less. The extinguisher and nacelle were positioned so that the wind direction was from the firefighters' back and towards the nacelle, plus or minus 30 degrees.

3.1.1. Rear Engine Fire Tests

Rear engine fire tests were conducted as outlined below, and consisted of a pretest phase, in which a the nacelle was first preheated to a specified temperature (Figure 5), and then a certain amount of fuel was allowed to flow into the nacelle and onto the concrete pad (Figure 3), followed by test phase, in which the firefighter attempted to extinguish the fire (Figure 6).

Pretest Phase

- Determine and record extinguisher full weight.
- Initiate flow of JP-8 through the afterburner nozzle (nozzle 3) at a flow rate of 2 gpm.
- Ignite fuel.
- Heat tail pipe to 550 ± 25 °F.
- Shut off fuel.

- Allow metal to cool to 475 ± 25 °F.
- Initiate fuel flow through nozzles 2 (2 gpm) and 3 (2 gpm) at a total flow rate of 4 gpm.
- Flow 25 gal of JP-8 through the fixture into the concrete pan.
- If spontaneous ignition occurs, shut off fuel and allow metal to cool to a lower temperature. Then resume flowing JP-8 fuel.

Figure 5. The F-100 Nacelle Mockup during the Pre-Burn Phase of a Rear Engine Fire Test

Test Phase

- Ignite low-pressure turbine and afterburner fuel sprays with a suitable torch applied through the ignition port.
- Ignite fuel in the pan on the ground with a suitable torch.
- Allow the fuel to burn for 15 s.
- Apply fire extinguisher according to manufacturer's instructions.
- Record
    - Time to extinguish.
    - Weight of agent used.
    - Weight of extinguisher after test.

Figure 6. A Firefighter Applying Agent into the F-100 Nacelle Mockup during a Rear Engine Fire Test

3.1.2. Access Panel Fire Tests

Access panel fire tests were conducted as outlined below, and consisted of a pretest phase in which the nacelle was preheated, followed by test phase, in which the firefighter attempted to extinguish the fire (Figure 7). Unlike the rear engine fire test, during the access panel fire test it was necessary for the firefighter to direct agent into the side panel of the nacelle to extinguish fire that developed in the nacelle annulus. The intent of this test is to simulate a hidden fire in an engine nacelle.

Pretest Phase

- Determine and record extinguisher full weight.
- Initiate flow of JP-8 through the afterburner nozzle (nozzle 3) at a flow rate of 2 gpm.
- Heat tail pipe to 550 ± 25 °F.
- Shut off fuel.
- Initiate fuel flow through nozzle 1 at a flow rate of 4 gpm.

Test Phase

- If spontaneous ignition does not occur, ignite access panel spray with a suitable torch applied between the engine shell and nacelle shell at the bottom rear of the fixture.
- Allow the fuel to burn for 15 s.
- Apply fire extinguisher according to manufacturer's instructions.
- Record
    - Time to extinguish.
    - Weight of agent used.
    - Weight of extinguisher after test.

Figure 7. A Firefighter Applying Agent Through the Side Panel of the F-100 Mockup during an Access Panel Fire Test

3.2. Stream Reach Tests

Stream Reach tests were performed inside the fire hangar (9500E) located at the AFCEC Test Range II (Sky X) test site. Stream reach was determined based on the ability to extinguish small fires at given distances. Testing was conducted indoors with no perceptible ambient wind. Five small steel cups (approximately 3-in diameter × 2-in tall) were placed on level ground at measured distances of 20, 25, 30, 35, and 40 ft from the agent discharge nozzle (Figure 8, left). Each cup was filled with 0.5 in of JP-8 on top of 1 in of water. After a pre-burn period of at least 15 s for the last cup ignited, a firefighter attempted to use the extinguisher to extinguish as many cups as possible. The firefighter was required to remain at a fixed location, and to hold the extinguisher nozzle at hip height (Figure 8, right). However, variation in nozzle elevation during discharge was permitted.

Figure 8. Fuel Cups Positioned At 5-ft Intervals from the Amerex Extinguisher (Background) (left); Firefighter Discharges the Extinguisher into/over the Cups (right)

4. RESULTS AND DISCUSSION

4.1. Rear Engine Fire Tests

A total of eleven rear engine fire tests were performed. Test 3 was deemed invalid due to a structural defect that developed in the F-100 nacelle during the test. The results from test 3 are therefore not included in the analysis of extinguishing performance, but are included in some of the statistical analysis presented later in this section. Of the remaining ten tests, the extinguisher successfully extinguished the fire in nine tests.

Table 3 summarizes the results of the rear engine fire tests performed with the Amerex 775 extinguisher. Temperature, wind speed, and humidity are values measured by the Kestrel weather meter just before the start of the test. Extinguishment time, the time between the start of agent application and extinguishment of all visible fire, was obtained from the video footage. Discharge time and quantity discharged were obtained from balance data recorded by the data acquisition system. Average discharge rate is the quantity discharged divided by the discharge time.

Table 3. Summary of Data from the Rear Engine Fire Tests; Data in Parenthesis Are Excluded from the Statistical Analysis in the Last Four Rows of the Table

Test Number	Temp (°F)	Wind Speed (mph)	Humidity (%)	Extin-guish Time (s)	Dis-charge Time (s)	Qty Dis-charged (lb)	Average Dis-charge Rate (lb/s)	Extin-guished
1	61.1	1.8	68.1	21		123		Yes
2	58.5	0.0	89.5	20	25	132	5.28	Yes
3	(60.1)	(2.6)	(78.2)	(NA)	(25)	(145)	(5.1)	NA
4	68.2	5.3	73.7	(NA)	(29)	(146)	(4.3)	No
5	69.2	6.2	75.5	22	21	122	5.81	Yes
6	67.6	6.7	76.8	22	22	139	6.32	Yes
7	58.3	2.6	64.1	20	20	138	6.90	Yes
8	59.3	4.6	25.5	24		148		Yes
9	58.9	5.0	24.5	21	22	139	6.32	Yes
10	59.5	2.9	89.8	18	19	121	6.37	Yes
11	68.1	1.1	88.3	18	20	124	6.20	Yes
Average	62.6	3.5	68.5	20.7	21.3	131.8	6.2	
Standard Deviation	4.6	2.2	23.1	1.9	2.0	9.7	0.5	
Relative Standard Deviation	7.3 %	61.5 %	33.7 %	9.4 %	9.3 %	7.4 %	8.2 %	
Relative Standard Error	2.3 %	19.5 %	10.6 %	3.1 %	3.5 %	2.5 %	1.3 %	

During tests 3 and 4, the tests in which the firefighter failed to extinguish the fire, the firefighter discharged the extinguisher 25 and 29 s before ceasing. Data recorded by the scale revealed that very little mass was lost from the extinguisher during the last several seconds of discharge. The long discharge time and low average discharge rate were therefore excluded from Table 3 to prevent them from skewing the average values and standard deviations of the successfully extinguished fires. In addition, the data acquisition system recording the scale readings failed during tests 1 and 8. Therefore some of the statistical analysis that follows included only the remaining seven tests.

4.1.1. Extinguishment Time

The Amerex extinguisher successfully extinguished nine of ten rear engine fires. The average extinguishment time for the nine successful attempts was 20.7 s with a standard deviation of 1.9 s, compared to an average extinguishment time of 16.6 s, with standard deviation of 9.9 s, for Halon 1211.

Although the firefighter performing the test was very experienced in performing rear engine fire tests, it could still be expected that as the firefighter performed successive tests with this particular extinguisher that the extinguishment times would tend to decrease as the firefighter became accustomed to the unique features of the extinguisher and agent. Figure 9 presents a plot of extinguishment time vs. test for the nine successfully extinguished fires and a least squares linear curve fit of the data. The Pearson product-moment correlation coefficient for this data set is -0.33, indicating the extinguishment time is weakly and negatively correlated to the test number. In other words, the extinguishment time tended to decrease with each successive test, but the correlation is low.

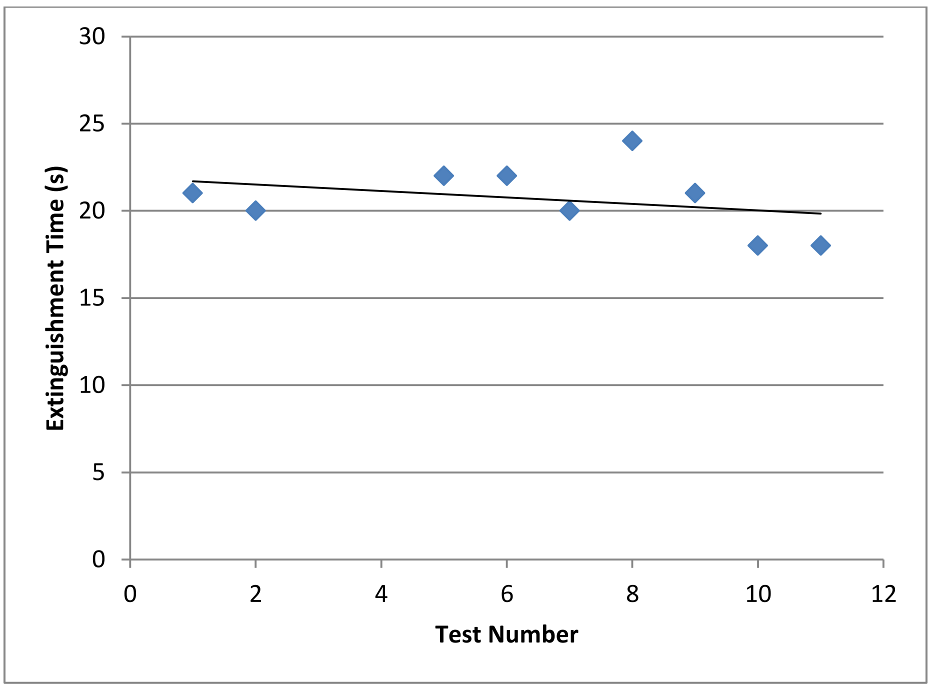

Figure 9. Plot of Extinguishment Time vs. Test Number for the Nine Succesfully Extinguished Rear Engine Fires

The correlation between extinguishment time and ambient wind speed, temperature, and humidity can similarly be examined. Table 4 presents the Pearson product–moment correlation

DISTRIBUTION A: Approved for public release; distribution unlimited. AFCEC-201501; 7 January 2015 coefficients for the correlation between extinguishment time and these three parameters, as well as the coefficient for test number, described above. This quantity varies between +1 and -1, indicating total positive and negative correlation, respectively, while a value of 0 indicates that no correlation exists. The extinguishment time is moderately positively correlated (+0.62) with wind speed – higher wind conditions resulted in longer extinguishment times, and moderately negatively correlated (-0.65) with humidity – higher humidity conditions resulted in lower extinguishment times. Essentially zero correlation (+0.03) existed between extinguishment time and ambient temperature, although testing occurred over a limited range of temperatures (58.3 to 68.1 °F).

Table 4. Pearson Product–Moment Correlation Coefficients for the Correlation between Rear Engine Fire Extinguishment Time and Four Parameters

Parameter	Range Encountered During Testing	Correlation Coefficient
Test Number	1–11	-0.33
Wind Speed	0–6.7 mph	+0.62
Temperature	58.3–68.1 °F	+0.03
Humidity	24.5–89.8 %	-0.65

4.1.2. Reignition

No reignition occurred in any of the nine tests where the extinguisher successfully put out the fire.

4.1.3. Quantity of Agent Consumed

The Amerex model 775 extinguisher has a capacity of 150 lb. Of the nine tests in which the fire was successfully extinguished, the average discharged weight was 131.8 lb (88 percent of full capacity) with a standard deviation of 9.7 lb, compared to an average discharged weight of 66.2 lb (44 percent of full capacity) and standard deviation of 21.3 lb for the Halon 1211 extinguisher from previous tests.

The Amerex model 775 extinguisher has a nominal capacity of 150 lb of Novec 1230. In addition, it was noted that approximately 2 lb of nitrogen gas was needed to pressurize the extinguisher to the required 125 psi. During tests 3 and 4 the firefighter completely discharged the extinguisher without extinguishing the fire. For those tests, the scale recorded a mass loss of 145 lb and 146 lb, respectively. It appears that a small amount of agent remains in the extinguisher after all the pressurizing gas is expelled. This was also noted when servicing the extinguisher between tests. After removing the hose and valve, the extinguisher still had a noticeable volume of liquid at the bottom of the cylinder.

4.1.4. Comparison with Previously Tested Hardware/Agent Combinations

The Amerex/Novec system extinguished nine of ten rear engine fires. The quantity of agent required to extinguish the fires varied from 121 to 148 lb, averaging 131.8 lb of agent used. Extinguishment times varied from 18 to 24 s, for an average extinguishment time where successful of 20.7 s. Table 5 summarizes these results, and presents the results from rear engine tests using Halon 1211 and several other extinguisher/agent combinations obtained from references (1) and (5).

Table 5. Comparison of Rear Engine Fire Test Results

Extinguisher Manufacturer / Agent	Number of Test Fires Extinguished	Range of Agent Used to Extin-guish Fire (lb)	Average Qty of Agent Used to Extinguish Fire (lb)	Range of Extin-guishment Times (s)	Average Extin-guishment Time (s)
Halon 1211	23 of 25 (92%)	36 – 113	66	9 – 51	17
Amerex/Novec 1230	9 of 10 (90%)	121 – 148	132	18 – 24	21
Ansul/FE-36	4 of 10 (40%)	111 – 144	131	17 – 23	20
Buckeye /Halotron	3 of 10 (30%)	92 – 114	107	16 – 21	19
Amerex /Halotron	3 of 10 (30%)	73 – 135	103	17 - 44	29

4.2. Access Panel Fire Tests

A total of ten access panel fire tests were performed. Nine fires were successfully extinguished, one was not extinguished.

Table 6 summarizes the results of the access panel fire tests performed with the Amerex 775 extinguisher. Temperature, wind speed, and humidity are values measured by the Kestrel weather meter just before the start of the test. Extinguishment time, the time between the start of agent application and extinguishment of all visible fire, was obtained from the video footage. The quantity of agent discharged was obtained from balance data recorded by the data acquisition system.

In the rear engine fire tests, the firefighter extinguished the fire with one continuous discharge of agent. However, in the access panel fire tests, the firefighter applied two or more short bursts of agent while moving around the F-100 mockup. Because the discharge was not continuous in the access panel tests, the discharge time and average discharge rate were not calculated.

Table 6. Summary of Data from the Access Panel Fire Tests—Data in Parenthesis are Excluded from the Statistical Analysis in the Last Five Rows of the Table

Test Number	Temp (°F)	Wind Speed (mph)	Humidity (%)	Extinguish Time (s)	Quantity Discharged (lb)	Extin-guished
1	59.5	2.9	89.8	18	106	Yes
2	68.1	1.1	88.3	13	104	Yes
3	77.6	1.1	32.2	(DNE)	(149)	No
4	82.3	2.8	80.9	17	88	Yes
5	84.7	1.9	72.6	19.5	91	Yes
6	85.2	1.0	66.6	15.5	84	Yes
7	85	3.8	77.5	12	60	Yes
8	82.7	1.8	82.7	13	63	Yes
9	85	3.5	79.3	14	59	Yes
10	85.1	1	78.1	13.5	70	Yes
Average	79.5	2.09	74.8	15.1	80.5	
Standard Deviation	8.8	1.1	16.4	2.6	18.3	
Relative Standard Deviation	11.1 %	51.8 %	22.0 %	17.2 %	22.7 %	
Standard Error	2.8	0.3	5.2	0.9	6.1	
Relative Standard Error	3.5 %	16.4 %	6.9 %	5.7 %	7.6 %	

4.2.1. Extinguishment Time

The Amerex extinguisher successfully extinguished nine out of ten fires access panel fires. The average extinguishment time for the nine successful attempts was 15.1 s with a standard deviation of 2.6 s.

The correlation between extinguishment time and test number, ambient wind speed, temperature, and humidity were examined by calculation of the Pearson product–moment correlation coefficient for these parameters. Table 7 presents the Pearson product–moment correlation coefficients for the correlation between extinguishment time and these four parameters. The extinguishment time is moderately negatively correlated (-0.49) with test number—the extinguishment time tended to decrease each successive test as the firefighter became more experienced with this fire scenario. Little to no correlation is seen between extinguishment time and wind speed, temperature, or humidity.

Table 7. Pearson Product-Moment Correlation Coefficients for the Correlation Between Access Panel Fire Extinguishment Time and Four Parameters

Parameter	Range Encountered During Testing	Correlation Coefficient
Test Number	1 – 10	-0.49
Wind Speed	1 – 3.8	+0.00
Temperature	59.5 – 85.2	-0.22
Humidity	32.2 – 89.8	-0.13

4.2.2. Reignition.

No reignition occurred in any of the nine tests where the extinguisher successfully put out the fire.

4.2.3. Quantity of Agent Consumed.

The Amerex model 775 extinguisher has a capacity of 150 lb. Of the nine tests in which the fire was successfully extinguished, the average discharged weight was 80.5 lb (54 percent of full capacity) with a standard deviation of 18.3 lb.

4.2.4. Comparison with Previously Tested Hardware/Agent Combinations

The Amerex/Novec system extinguished nine of ten access panel fires. The quantity of agent required to extinguish the fires varied from 59 to 106 lb, with an average of 80.5 lb of agent used. Extinguishment times varied from 12 to 19.5 s, for an average extinguishment time when successful of 15.1 s. Table 8 summarizes these results, and presents the results from rear engine tests using Halon 1211 obtained from references (5).

Table 8. Comparison of Access Panel Fire Test Results

Extinguisher Manufacturer/ Agent	Number of Test Fires Extinguished	Range of Agent Used to Extinguish Fire (lb)	Avg Qty of Agent Used to Extinguish Fire (lb)	Range of Extin-guishment Times (s)	Average Extin-guishment Time (s)
Halon 1211	8 of 10 (80%)		81.8		17.3
Amerex/Novec 1230	9 of 10 (90%)	59 - 106	80.5	12 – 19.5	15.1

4.3. Stream Reach Tests

One stream reach test was performed using the Amerex model 775 extinguisher. Stream reach was estimated based upon the ability of the extinguisher to extinguish small cups containing burning JP-8 fuel as described in section 3.2. Cups were positioned at 5-ft intervals from 20-ft through 40-ft distance from the extinguisher. The extinguisher demonstrated the ability to extinguish the cups of burning fuel at a distance of at least 30 ft from the nozzle in still air.

Previous stream reach tests on the DOD/Halon 1211, Ansul/FE-36, Amerex/Halotron-1, and Buckeye/Halotron-1, extinguisher/agent combinations established that the stream reach in each case was a minimum of 35 ft. The Amerex/Novec 1230 extinguisher/agent combination is therefore comparable to these other systems in terms of stream reach.

5. CONCLUSIONS

The Amerex model 775 wheeled extinguisher containing the Novec 1230 firefighting agent was evaluated by conducting a test series consisting of ten rear engine fire tests, ten access panel fire tests, and one stream reach test.

- The Amerex extinguisher successfully extinguished nine of ten rear engine fires. Extinguishment times for the nine successful tests varied from 18 to 24 s, with an average extinguishment time of 20.7 s. For extinguished test fires, the amount of Novec discharged varied from 121 to 148 lb (81 to 99 percent of full extinguisher capacity), with an average amount discharged of 132 lb (88 percent of full capacity). Extinguishment times were noted to be moderately correlated with the ambient wind speed and ambient humidity. No correlation with ambient temperature was observed.
- The Amerex extinguisher successfully extinguished nine of ten access panel fires. Extinguishment times for the nine successful tests varied from 12 to 19.5 s, with an average extinguishment time of 15.1 s. For extinguished test fires, the amount of Novec discharged varied from 60 to 106 lb (40 to 71 percent of full extinguisher capacity), with an average amount discharged of 80 lb (54 percent of full capacity). Extinguishment times were noted to be moderately correlated with the test number. No correlation with ambient temperature, humidity, or wind speed was observed.
- One stream reach test was performed. The extinguisher demonstrated the ability to extinguish small fires at a distance of at least 30 ft from the nozzle. This exceeded the requirement of 25 ft set forth in a previous joint Air Force–Navy project

6. RECOMMENDATIONS

Serious consideration should be given to the Amerex model 775 extinguisher with Novec 1230 as a replacement for the current Halon 1211 flightline extinguisher. Aspects like material compatibility and life-cycle cost of the extinguisher will have to be studied before a final decision is made, but the performance of the extinguisher on test fires combined with the fact that the EPA has included Novec 1230 in its SNAP list as a clean agent forms a strong argument for making the model 775 an acceptable alternative to the current extinguisher.

A project to investigate the practicality and performance of Novec 1230 in an ultra-high-pressure (UHP) extinguisher is recommended. UHP technology has been shown to be more efficient than conventional extinguishers in applications that share many characteristics with flightline fires, and a portable UHP system of size comparable to the Model 775 might exhibit better performance than the Model 775.

Local guidance in technical report, AFRL-ML-TY-TR-02-4540—*Minimum Performance Requirement for Air Force Flightline Fire Extinguishers: Extinguishing Performance Against 3-Dimensional and Hidden Fires*, should be reviewed and, if appropriate, updated. The report was written at a time when it was thought that research would soon produce an environmentally safe substitute for Halon 1211 with comparable firefighting performance. Given that in the 12 years since the report was written no such substitute has been discovered, consideration should be given to adopting different acceptance criteria.

7. REFERENCES

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

°C	degrees Celsius
°F	degrees Fahrenheit
atm	atmosphere (pressure)
AFCEC	Air Force Civil Engineering Center
AFRL	Air Force Research Laboratory
Btu	British thermal unit
cm^3	cubic centimeter
DLA	Defense Logistics Agency
DOD	Department of Defense
DOT	Department of Transportation
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
ft	feet
ft^3	cubic feet
ft^3/lb	cubic feet per pound
g	gram
gal	gallon(s)
g/ml	grams per mililiter
g/mol	gram per mole (quantity)
gpm	gallons per minute
GWP	global warming potential
kJ/kg	kilojoules per kilogram
lb	pound
lbm	pound-mass
lbm/ft^3	pound-mass per cubic feet
lb/s	pound per second
m	meter
mph	miles per hour
NFPA	National Fire Protection Association
NOAEL	no observed adverse effect level
ODP	ozone depletion potential
ODS	ozone depleting substance
psi	pounds per square inch
psig	pounds per square inch gage
s	second
SNAP	Significant New Alternatives Policy
UHP	ultra-high-pressure
UL	Underwriters Laboratories
USAF	United States Air Force
wt	weight